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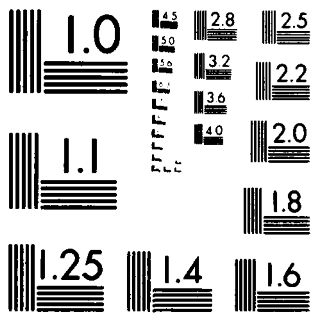

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Nonlinear Large-Amplitude Low-Frequency Ship Motions

by

Nils Salvesen

April 1982

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A new nonlinear time-domain method for predicting large amplitude motions for a ship advancing in a seaway has been developed. The seaway is represented by a second-order Stokes wave. A consistent nonlinear theory is derived by assuming that the frequency of encounter is small. Results obtained by computer codes show good agreement with linear theory for small-amplitude waves, whereas large differences are found between the nonlinear method and linear theory for steeper waves.

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ACKNOWLEDGMENT

All of the work presented here has been supported by the Department of the Navy. The initial work on this project started in the spring of 1979 while I was at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) in Bethesda, Maryland. The initial part was supported by the Numerical Naval Ship Hydrodynamic Program at DTNSRDC.

During the academic year 1979-80, I was honored to be appointed to the NAVSEA Visiting Research Professor Chair at the U.S. Naval Academy in Annapolis, Maryland. The major part of the work reported here was done during my stay at the Academy. Ms. Nadine M. White, who was my computer assistant during this period, was supported by a grant from the Office of Naval Research (ONR Contract #N00014-80-C-0168).

In the summer of 1980, I joined Science Applications, Inc. (SAI), and continued to work on this problem area with support from ONR (Continuation Contract #N-00014-80-C-0168).

This report presents the progress on this work through December 1980. This work is now being continued at SAI with support from ONR.

I would like to use this opportunity to express my thanks to the Naval Academy and to NAVSEA for the year I spent at the Academy. It was a rewarding year not only with respect to my research work, but also, through teaching naval architecture and coaching sailing , it gave me an opportunity to work closely with the midshipmen. I am impressed both by the Academy's high academic standards and their excellent military training. Most importantly, the year at the Naval Academy gave me a renewed confidence in the future of the U.S. Navy.

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ABSTRACT

A new nonlinear time-domain method for predicting large amplitude motions for a ship advancing in a seaway has been developed. The seaway is represented by a second-order Stokes wave. A consistent nonlinear theory is derived by assuming that the frequency of encounter is small. In this theory, the added-mass, damping, and diffraction terms are obtained by linear theory, whereas the nonlinear hydrostatic restoring and Froude-Kriloff forces are predicted by integrating the pressures over the instantaneous wetted surface of the hull. Computer codes have been developed which predict the non-linear large-amplitude motions in the time domain for a ship advancing in beam, head, and following seas. Results obtained by these computer codes show good agreement with linear theory for small-amplitude waves, whereas large differences are found between the nonlinear method and linear theory for steeper waves.

Section 1

INTRODUCTION AND SUMMARY

1.1 Background

1.1.1 Linear Ship-Motion Theories

During the last twenty years, it has been demonstrated that linear ship-motion strip theory (for example, Salvesen, Tuck, and Faltinsen, 1970) can solve with good accuracy many seakeeping problems related to the average performance of ships in moderate sea conditions. As the sea condition becomes more and more severe, however, the linearized frequency-domain strip-theory approach becomes inadequate for analyzing most of the important seakeeping problems. More importantly, however, the linearized approach cannot be used to forecast some of the most important responses of a ship even in moderate sea conditions. For example, relative bow motions in any heading cannot be predicted accurately by linear strip-theory ship-motions computer programs.

Strip theory not only linearizes the free-surface boundary conditions and the ship-bull boundary condition, but it also replaces the three-dimensional hydrodynamic problem by a summation of two-dimensional sectional problems. At present, it is not clear which of the above three approximations of linear strip theory is most responsible for the significant errors in the predicted ship-motion results. Ming Chang (1977) has developed a fully three-dimensional ship-motion theory in which, similar to linear strip-theory, both the free-surface boundary conditions and the hull-boundary

conditions are linearized. Some of the unpublished work has shown that there are only small differences between the heave and pitch motions predicted by the three-dimensional theory and by conventional linear strip theory. These preliminary results seem to indicate that the inaccuracy of the linear strip theory is due primarily to the approximation that the amplitude of ship motion is so small that the wetted surface of the hull remains fixed over the period of ship motion. Such an approximation is compatible with "wall-sided" geometric characteristics of ship section shapes, even for moderate amplitude ship motions. However, most ships incorporate a considerable amount of flare in the ship sections near the bow and stern. Such geometric characteristics cause substantial nonlinear hydrodynamic effects, particularly in the pitching motions of the ship. These nonlinear effects can be accounted for by modifying the linear strip theory to compute the hydrodynamic characteristics of the ship as a function of time and allowing for the instantaneous position of the ship. Furthermore, the linear strip theory cannot account for the changing lateral forces and moments arising from the changing wetted surface of the ship as it heaves and pitches. Hence, the important coupling between the heave-pitch and the sway-yaw motions is missing, but this coupling can be accounted for in a nonlinear strip theory which does allow for changing wetted surface as the ship oscillates.

The important point to consider is that the motions of a ship are rarely as small as the assumptions of linear strip-theory require. For example, Figure 1 below shows the bow motions that were computed using linear strip theory for a destroyer hull in regular waves with the very modest value of steepness, $H/\lambda = 0.013$ (where H is the wave height and λ is the wave length).

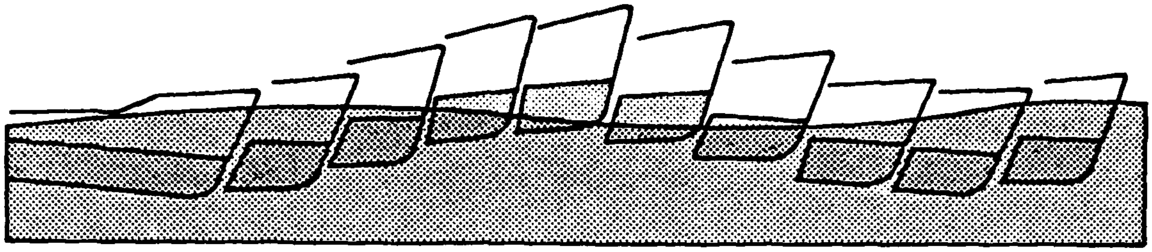


Figure 1: Bow Motion of Destroyer Hull in Sinusoidal Wave with Wavelength, λ = 1.20L, Waveheight, H/λ = 0.013, and Froude Number, F_n = 0.35 (Salvesen, 1978).

Note the substantial changes of bow immersion over a cycle of the ship motion. Clearly, such large excursions of the bow relative to the mean level of the water violates the basic assumptions of linear strip theory. It is intuitively obvious that such large changes of bow immersion will entail tremendous pitch-yaw coupling effects that are completely missing in the standard linear strip theory of ship motions. It is precisely this aspect of the linear strip theory that we feel is in the most urgent need of improvement.

1.1.2 Nonlinear Ship-Motion Theories

The formulation of the nonlinear ship-mosion problem is so complicated that there have been few attempts to develop computational methods for solving such fully three-dimensional problems. Paulling's (1974) attempt is one of the few exceptions. He assumed that the frequency of encounter is low enough that all he needs to account for is the large amplitude hydrostatic effects. He uses very simple approximations to the hydrodynamic effects. Paulling has had some success with this method in determing the capsizing of ships due to low cycle roll response in following seas. However, this simplified method cannot be used to predict the hydrodynamic loading on ships

since the local hydrodynamics are not computed with the accuracy needed to determine local pressure distributions. Salvesen (1978) has formulated a second-order strip theory for predicting large amplitude ship motions, but has not presented any numerical results obtained by using this theory.

There is a need for a new computational method for predicting ship motions which takes into account the most important nonlinear hydrodynamic effects associated with large amplitude motions. However, little progress has been made towards this goal since it is so difficult to reduce the complicated nonlinear three-dimensional mathematical formulation to a simpler form from which a computationally feasible computer program can be developed. This requires the determination of those nonlinear effects which must be included and those which can be disregarded without a substantial loss of the accuracy required to predict the observed ship motions.

1.2 Summary of New Nonlinear Method

1.2.1 Objective

The objective of this work has been to develop a new method and appropriate computer program for predicting the nonlinear large-amplitude motions for a "non-wall-sided" ship advancing in a seaway. The local hull form above and below the still water has been accounted for so that phenomena such as bow-flare impact, slamming and the shipping of water on deck as well as the ship motions themselves can be predicted with fair accuracy in relatively severe sea conditions.

1.2.2 Theoretical Method

A new nonlinear time-domain "strip-theory" calculation method for ship motions is outlined in Section 2. In this method it is assumed that the frequency of encounter is sufficiently small so that the inertia, damping, and diffraction forces are much smaller than the hydrostatic restoring and the Froude-Kriloff exciting forces. The added-mass, damping, and diffraction terms in the equation of motion are then predicted by the conventional linear ship-motion theory, whereas the hydrostatic restoring and Froude-Kriloff forces are computed by integrating the pressure over the instantaneous wetted hull surface at each time step.

The low-frequency assumption restricts the applicability of the present method; however, it should be suitable for solving beam, quartering, and following sea problems. It should also be applicable to bow and head sea cases with low forward speed.

The most important reason for applying the low-frequency assumption and for using the linear-theory added-mass, damping, and diffraction terms is that this is a natural first step towards a more complicated nonlinear theory where the total two-dimensional sectional hydrodynamic problem is solved at each time step. Furthermore, as shown in the results, the low-frequency approach gives us some good realistic estimates of the magnitude of some of the nonlinear effects not included in the conventional linear strip-theory approach.

Section 2

THEORETICAL APPROACH

A ship advancing at constant mean forward speed in oblique waves is being considered. It is assumed that the frequency of encounter is sufficiently small so that large amplitude body motions will result only in small free surface disturbances. Let (x,y,z) be a right-handed orthogonal coordinate system fixed with respect to the mean position of the body, with z vertically upward through the center of gravity of the body, x in the direction of forward motion, and the origin in the plane of the undisturbed free surface.

2.1 Incident Wave

The incident wave is represented by a second-order Stokes wave with the velocity potential given by

$$\Phi_I = \Phi_I^{(1)} + \Phi_I^{(2)} + \ldots = \frac{iga}{\sigma} e^{-ikX} e^{kz} e^{i\omega t} \tag{2.1}$$

and the wave elevation by

$$\xi(X,t) = a\cos(kX + \omega t) + \tfrac{1}{2}ka^2 \cos 2(kX + \omega t) + \ldots \tag{2.2}$$

where

$$X = x\cos\beta + y\sin\beta.$$

Here a is the first-order wave amplitude, σ is the wave frequency, k is the wave number, β is the heading angle, and ω is the frequency of encounter.

Note that the expression (2.1) is correct to the second-order in wave amplitude, and we are using a notation such that $\Phi_I^{(1)}$ is of $O(\alpha)$ and $\Phi_I^{(2)}$ is of $O(\alpha^2)$ where α is a small parameter proportional to the wave slope.

2.2 Velocity Potential

It is assumed that the total velocity potential, $\Phi(x,y,z,t)$ has the following expansion

$$\Phi = \Phi_I^{(1)} + \Phi_I^{(2)} + \Phi_B^{(1,1)} + \dots \tag{2.3}$$

where the body disturbance potential, $\Phi_B^{(1,1)}$ is of $O(\alpha\delta)$ where δ is a small parameter related to the low encounter frequency and/or the slenderness of the body.

2.3 Equations of Motions

The equations of motion may be expressed as

$$\sum_{i=1}^{6} M_{ji}\, \ddot{\eta}_i = F_j^{POT} + F_j^{ADD} \quad , \; j = 1,2\dots6 \tag{2.4}$$

where i or j equal to 1, 2, 3, 4, 5, 6 refer to surge, sway, heave, roll, pitch, and yaw, respectively, and where M_{ji} is the generalized mass matrix, $\ddot{\eta}_i$ are the components of the acceleration of the center of gravity. Furthermore, F_j^{POT} are the forces and moment components resulting from the velocity potential (2.3), and F_j^{ADD} are additional force and moment components due to viscous drag, lift, and vortex shedding effects. Note that the moments are about the axis of a coordinate system parallel to the (x,y,z) system, with

the origin at the center of gravity of the body.

2.4 Hydrodynamic Forces

The hydrodynamic force and moment components on the body are

$$F_j^{POT} = \iint_{S_t} p n_j \, ds \tag{2.5}$$

where n_j are the components of the generalized normal and S_t is the instantaneous wetted hull surface. The pressure, p, is by Bernoulli's equation

$$p = -\rho\frac{\partial\Phi}{\partial t} - \frac{\rho}{2}|\nabla\Phi|^2 - \rho g z \tag{2.6}$$

If we only include terms of $O(\alpha)$, $O(\alpha^2)$, and $O(\alpha\delta)$, the second-order hydrodynamic force due to the velocity potential (2.6) alone is

$$F_j^{POT} = -\iint_{S_t} (\rho\frac{\partial}{\partial t}\Phi_I + \rho g z)\, n_j \, ds \tag{2.7}$$

$$-\iint_{S_0} \rho(\tfrac{1}{2}|\nabla\Phi_0^{(1)}|^2 + \frac{\partial}{\partial t}\Phi_B^{(1,1)})\, n_j \, ds$$

Here the first integral is over the instantaneous wetted surface, S_t, whereas the last integral is over the undisturbed position, S_0.

It is convenient to decompose the force, F_j^{POT} into the following components

$$F_j^{POT} = F_j^{FK} + F_j^{R} + F_j^{HD} + F_j^{D} + F_j^{DC} \tag{2.8}$$

where by equation (2.6) the Froude-Kriloff exciting force, F_j^{FK} and the hydrostatic restoring force, F_j^{R} are

$$F_j^{FK} + F_j^{R} = -\iint_{S_t} \left(\rho \frac{\partial}{\partial t} \Phi_I + \rho g z\right) n_j \, ds \,, \tag{2.9}$$

and the hydrodynamic forces, F_j^{HD}, and the diffraction exciting force, F_j^{D} are

$$F_j^{HD} + F_j^{D} = -\iint_{S_0} \rho \frac{\partial}{\partial t} \Phi_B^{(1,1)} n_j \, ds \,, \tag{2.10}$$

and, finally, the second-order DC force is

$$F_j^{DC} = -\iint_{S_0} \frac{\rho}{z} |\nabla \Phi_0^{(1)}|^2 n_j \, ds \,. \tag{2.11}$$

Since the body disturbance potential, $\Phi_B^{(1,1)}$ is of first order in α, this potential can be assumed to be harmonic. Hence, we may write

$$\Phi_B^{(1,1)} = (\xi_j \phi_j + \phi_D) e^{i\omega t} \tag{2.12}$$

where ϕ_D is the diffraction potential, and ϕ_j is the contribution to the potential from the jth mode of motion ξ_j. By substituting (2.11) into (2.9) it follows that

$$F_j^{HD} + F_j^{D} = -A_{ji} \ddot{\eta}_i - B_{ji} \dot{\eta}_i + F_j^{D} \tag{2.13}$$

where A_{ji} and B_{ji} are the added mass and damping coefficients. Within the present formulation of the problem, the terms, A_{ji}, B_{ji}, and F_j^{D}, can be computed by linear ship motion theory. Note that if strip theory gives inadequate estimates for these terms at low frequencies, a three-dimensional method may be used for the prediction of these linear hydrodynamic terms.

The total hydrodynamic force on the body consists of the parts of the potential force, F_j^{POT}, and the additional force, F_j^{ADD}, which has the

following components

$$F_j^{ADD} = F_j^{VD} + F_j^{L} + F_j^{VS} . \qquad (2.14)$$

Here F_j^{VD}, F_j^{L}, and F_j^{VS} are the forces due to viscous drag, lift, and vortex shedding, respectively.

2.5 Problem Formulation Summary

The equations of motion which are to be solved by a finite-difference time-simulation method are

$$\sum_{i=1}^{6} M_{ji}\ddot{\eta}_i = [F_j^{FK} + F_j^{R}] + [F_j^{D} - A_{ji}\ddot{\eta}_i - B_{ji}\dot{\eta}_i] \qquad (2.15)$$

$$+ F_j^{DC} + F_j^{VD} + F_j^{L} + F_j^{VS} , \quad j = 1,2\ldots6$$

where $F_j^{FK} + F_j^{R}$ are the nonlinear Froude-Kriloff and restoring forces given by equation (2.8), $[F_j^{D} - A_{ji}\ddot{\eta}_i - B_{ji}\dot{\eta}_i]$ are the linear diffraction, added mass, and damping terms, F_j^{DC} is the second-order DC force given by equation (2.11), and F_j^{VD}, F_j^{L}, and F_j^{VS} are the viscous drag, lift, and vortex shedding terms.

Section 3

COMPUTATIONAL METHOD

3.1 Completed Computer Codes

Two computer codes have been developed which determine the nonlinear large-amplitude ship motions in the time domain. One computer code predicts the heave, sway, and roll motions for a ship in beam seas, whereas the other code predicts the heave and pitch motions in head and following waves. In both of these codes, the incident wave is a second-order Stokes wave (see equations (2.1) and (2.2)). The diffraction force, F_j^D, and the added-mass and damping coefficients, A_{ij} and B_{ij}, respectively, are predicted for the particular frequency of encounter (note that the nonlinear Stokes wave is *periodic*) by linear ship-motion strip theory of Salvesen, Tuck, and Faltinsen (1970). The viscous damping terms are only included by an approximate value for roll damping. The Froude-Kriloff force, F_j^{FK}, and the diffraction force, F_j^D, are computed at each time step by integrating the pressure over the instantaneous wetted surface (see equation (2.9)).

3.2 Time Stepping Procedure

The motions of the ship are computed as a function of time by a numerical procedure in which the time, t, is advanced in small time steps, Δt. We shall suppose that the displacements, velocity, and acceleration components, $\eta_j(t)$, $\dot{\eta}_j(t)$, and $\ddot{\eta}_j(t)$, respectively, are known at time, t. When the time is advanced from t to $t + \Delta t$, the new displacement and velocity

components, can be determined from the known motions as follows:

$$\eta_j\,(t+\Delta t) = \eta_j(t) + \dot{\eta}_j(t)\cdot\Delta t + \tfrac{1}{2}\ddot{\eta}_j(t)\cdot(\Delta t)^2 \tag{3.1}$$

and

$$\dot{\eta}_j\,(t+\Delta t) = \dot{\eta}_j(t) + \eta_j(t)\cdot\Delta t\;. \tag{3.2}$$

Knowledge of the displacements, $\eta_j(t+\Delta t)$ and the velocities, $\dot{\eta}_j(t+\Delta t)$ allows one to compute the force component on the right-hand side of the equation of motion (2.15). One can then use the equation of motion (2.12) to compute the updated value of acceleration, $\ddot{\eta}_j(t+\Delta t)$.

This time stepping procedure seems to work well for the beam sea cases investigated. However, we encountered instabilities with this approach for following sea cases, and then introduced a second-order method where the displacement at time, $t + \Delta t$, is given by

$$\eta_j(t+\Delta t) = \eta_j(t) + \dot{\eta}_j(t)\,\Delta t + \frac{1}{6}\,[2\ddot{\eta}_j(t) + \ddot{\eta}_j(t+\Delta t)]\,(\Delta t)^2 \tag{3.3}$$

and the velocity by

$$\dot{\eta}_j(t+\Delta t) = \dot{\eta}_j(t) + \tfrac{1}{2}\,[\ddot{\eta}(t) + \ddot{\eta}(t+\Delta t)]\;\Delta t\;. \tag{3.4}$$

Note that the displacements and the velocities at time, $t + \Delta t$, are here expressed in terms of the unknown acceleration, $\ddot{\eta}(t+\Delta t)$, so that in this case, an iteration scheme has to be used for each time step. This approach resulted in stable solutions for most of the cases investigated with Δt equal to one twentieth of the period. However, we found that for some particular following sea cases with extremely low encounter frequency, it was difficult to reach

stable conditions. Other time stepping procedures will be considered in future work.

Section 4

RESULTS

Two ship hull forms were used to evaluate and to explore the potentials of the two new time-domain nonlinear large-amplitude computer codes for predicting:

(i) heave, sway, and roll motions in beam seas; and

(ii) heave and pitch motions in head and following seas.

The two hull forms used were the Series 60 form with block coefficient, $C_B = 0.70$, and a typical trawler form. The body plans for the Series 60 and the trawler form are shown in Figures 2 and 3, respectively. Eleven stations were used for each ship form. The selected segments used for each station are shown in the figures.

These two hull forms were selected since the Series 60 form is almost "wall-sided", whereas the trawler form has extreme "V" sections. It was felt that by using these hull forms the nonlinear effects strictly due to the large-amplitude motions could be separated from the effects strictly due to the "non-wall-sidedness".

4.1 Beam Sea Results

The accuracy of the beam sea computer code was first evaluated by using small amplitude waves (wave amplitude/draft ratio, $\alpha/D = 0.01$). The

Figure 2: Body Plane of Series 60, $C_B = 0.70$ Form with the Selected Segments for each of the Eleven Stations.

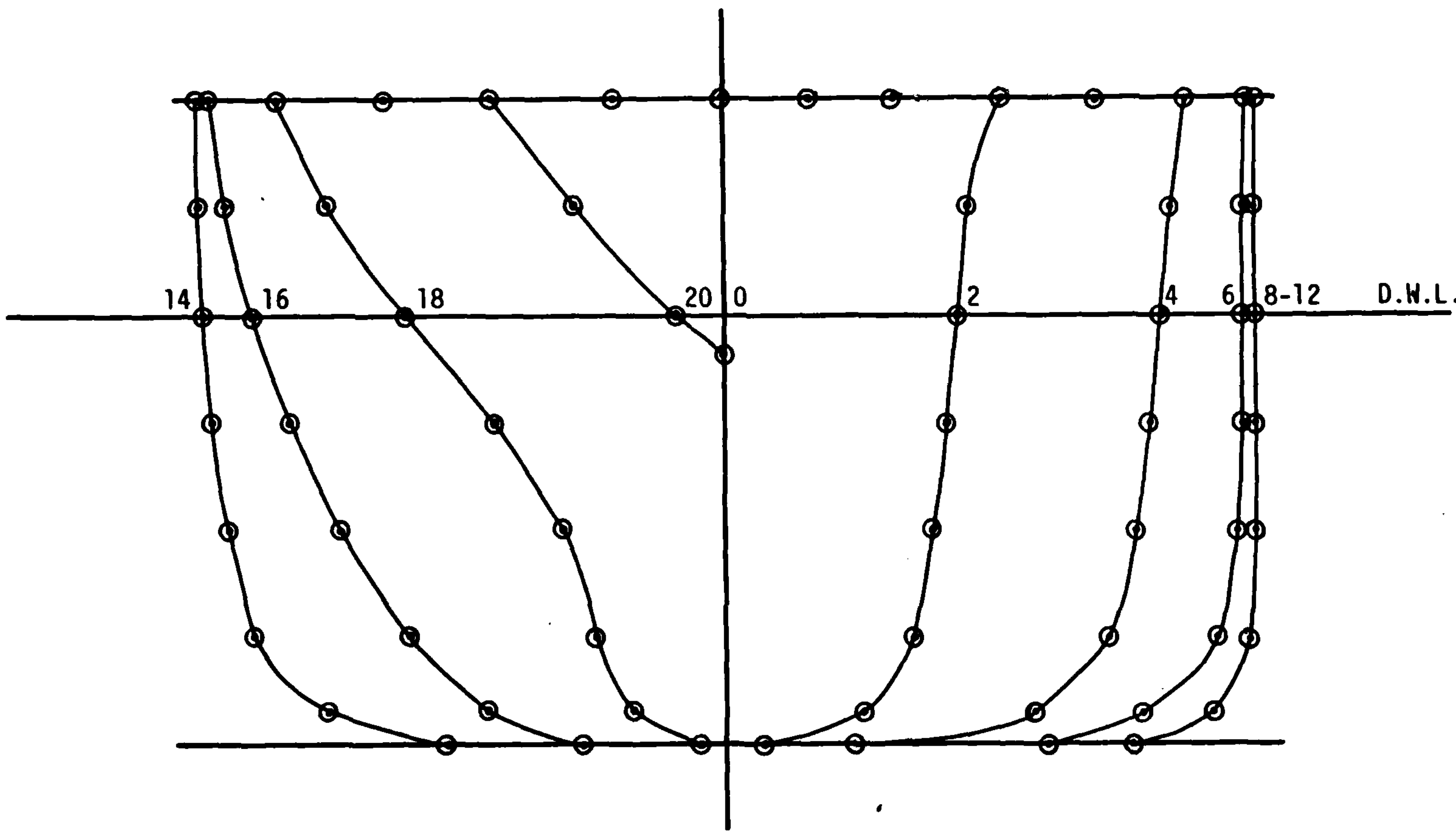
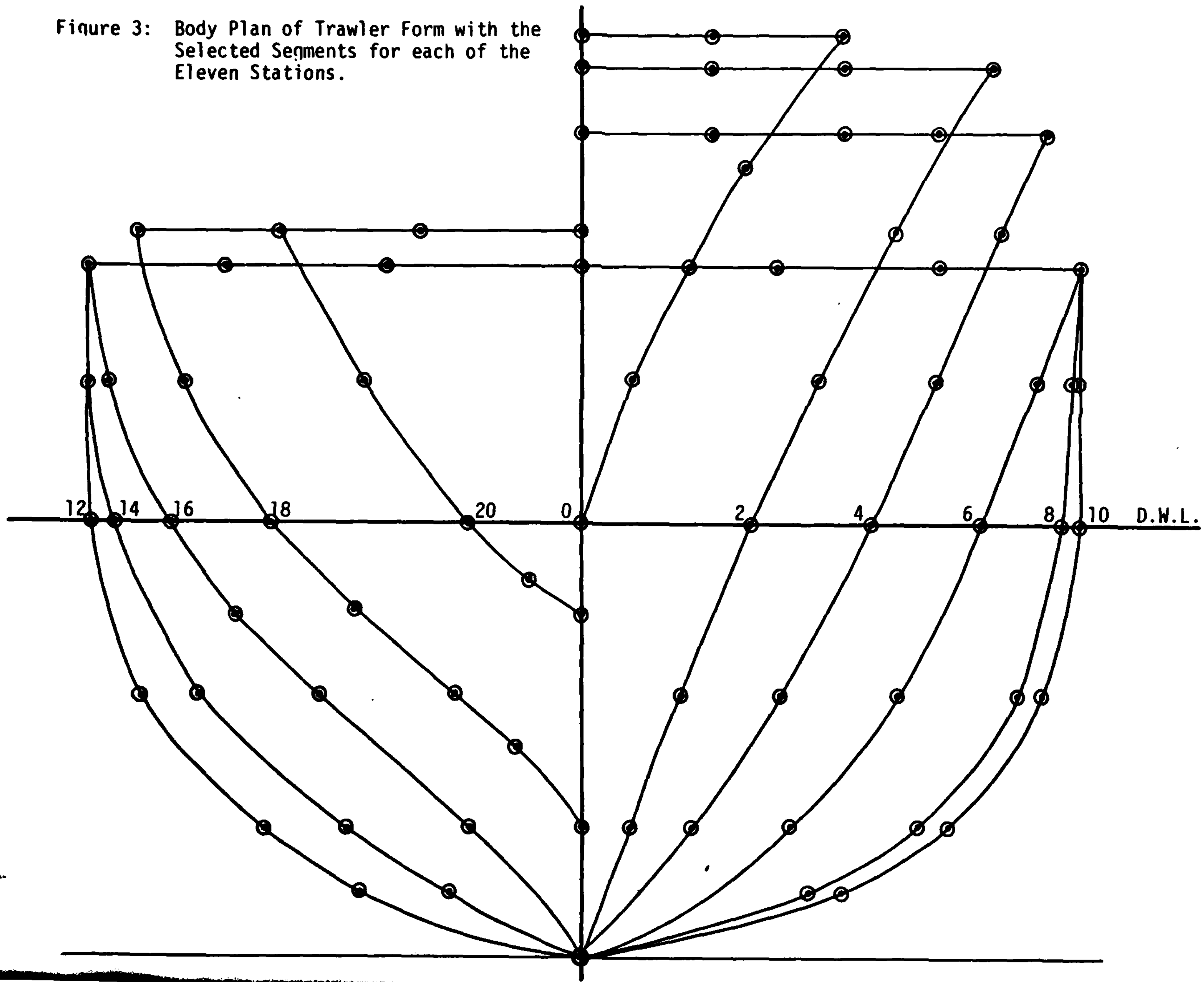


Figure 3: Body Plan of Trawler Form with the Selected Segments for each of the Eleven Stations.



pitch, heave, and roll motions predicted by the time-domain method were found for most of the wavelength cases investigated to agree within 1% of the results obtained by conventional linear frequency domain strip theory. For larger wave amplitudes, we found discrepancies between the nonlinear time-domain code and the linear frequency domain theory. Som sample results for the largest wave amplitude investigated ($\alpha/D = 0.50$) are shown in Figure 4. For this case, the maximum roll displacement is 29.7 degrees, and, as seen in the figure, the deck is partly submerged. The computed time-domain motions were periodic and stable for this large amplitude case, and the motions were about 20% different from the linear theory results. Computations were also made with larger wave amplitude; however, we then found that the results were somewhat unstable. These effects need to be further investigated.

Figure 5 shows the sway displacement, η_2 computed by the time-domain code as a function of time for the Series 60 hull in beam waves with $\alpha/D = 0.25$. The results clearly show the nonlinear drift which cannot be predicted by linear theory. The sway-displacement response shown in Figure 5 is approximately

$$\eta_2 = A_1 t + A_2 \cos \omega t$$

where $A_1 t$ is the nonlinear drift, and $A_2 \cos \omega t$ is the harmonic motion. The linear theory predicts a sway amplitude of 0.2035 for this case, whereas for the nonlinear time-domain results shown in Figure 5, we have that $0.2040 \leq A_2 \leq 0.2055$. These seem to indicate stable results which are in good agreement with linear theory.

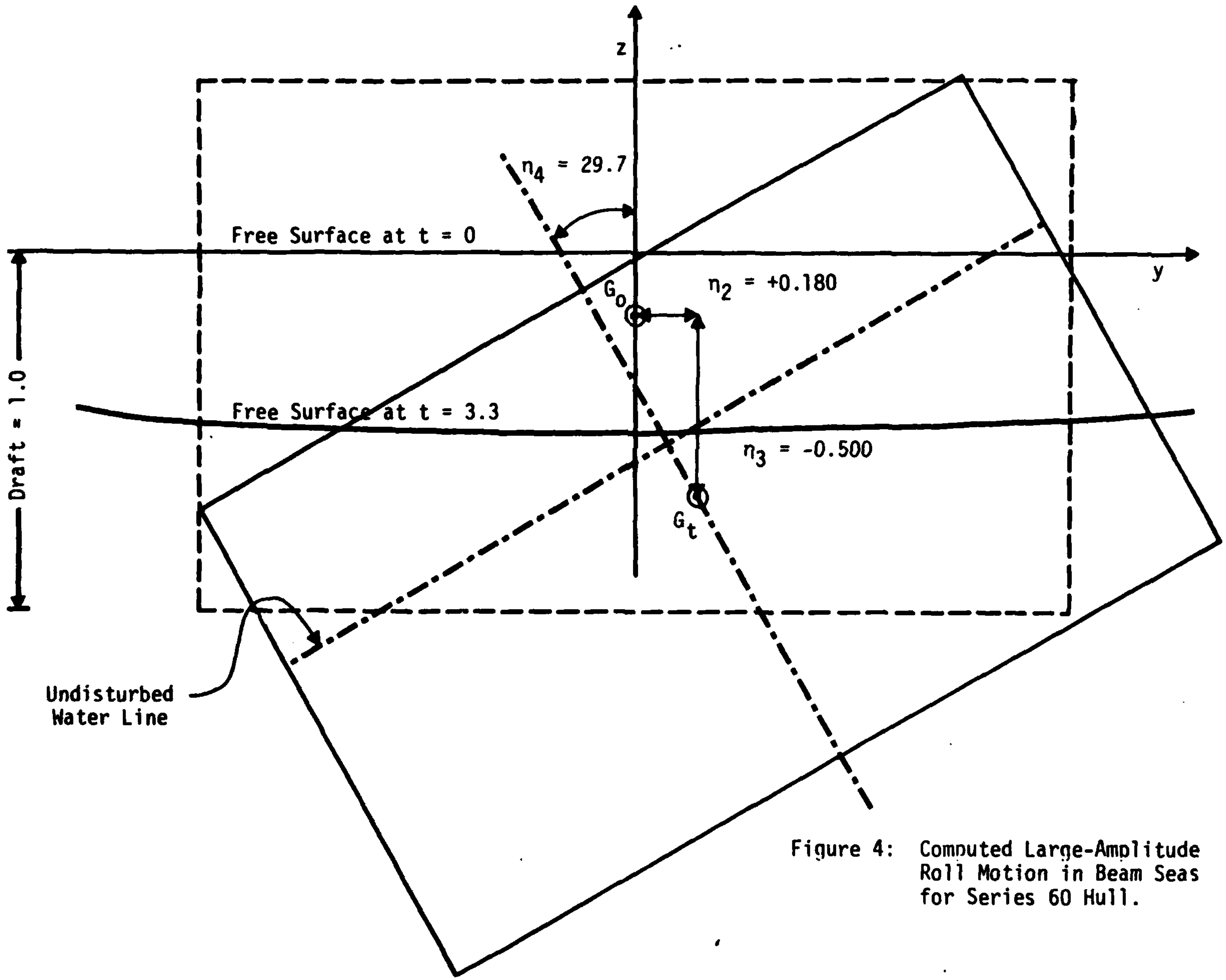


Figure 4: Computed Large-Amplitude Roll Motion in Beam Seas for Series 60 Hull.

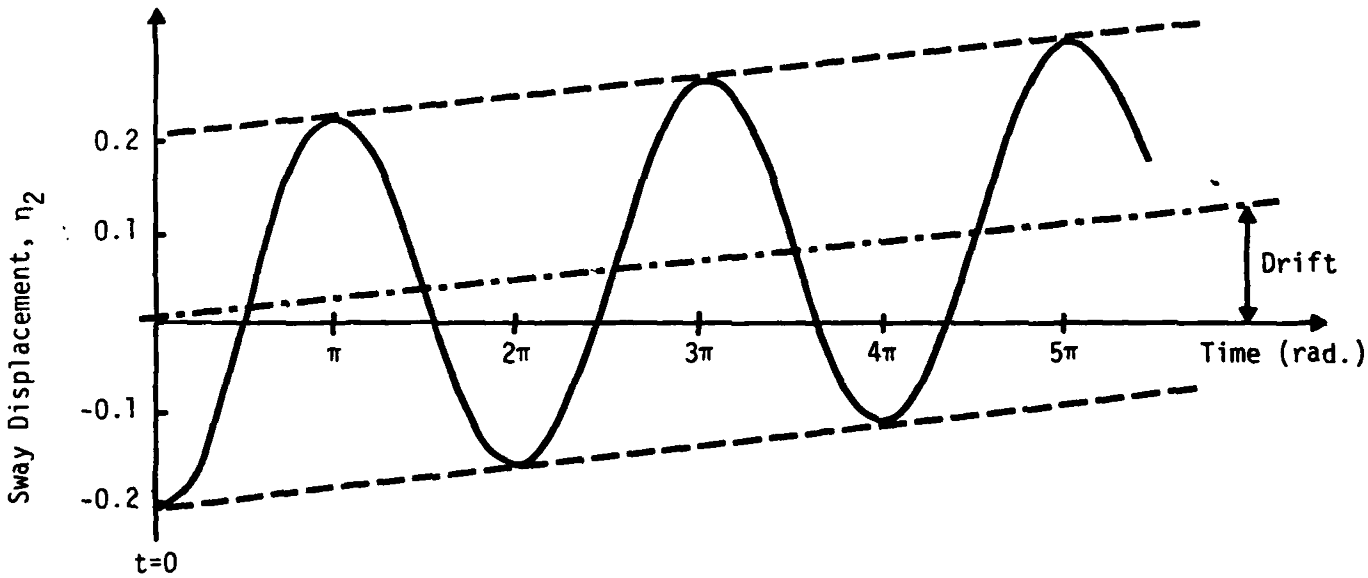


Figure 5: Computed Sway Displacement as a Function of Time for Series 60 Hull in Beam Waves with α/D = 0.25.

4.2 Head and Following Sea Results

The heave and pitch responses in head and following seas were investigated for both the Series 60 hull and the trawler form for several combinations of wave conditions and forward speeds. For small wave amplitudes ($\alpha/D = 0.01$), we found good agreement with linear theory and stable results other than for following sea cases with the frequency of encounter close to zero. For the very low frequency cases, the results were clearly unstable.

Large amplitude responses were also investigated and Figure 6 shows the difference in the heave displacements between the conventional linear strip theory and our new nonlinear time-domain computer code for the trawler at zero forward speed in head waves (ship length/wavelength ratio, $L/\lambda = 0.75$). It is seen that for a moderately steep wave with waveheight-to-wavelength ratio, $H/\lambda = 0.03$, the difference is 15% for the downward heave displacement and 5% for the upward displacement. For a steep wave with $H/\lambda = 0.09$, the differences are 36% and 19%, respectively.

In Figure 7, the corresponding results are presented for the Series 60 hull. The abrupt changes in the two curves are due to bow submergence at $H/\lambda \approx 0.035$. The effect of the water on deck is included in the computer code; however, it is questionable if the method in its present form gives a meaningful representation of the actual hydrodynamic effects associated with the large amount of water passing over the deck. This problem area needs to be further investigated.

Figure 6: Differences in Heave Displacements Between Linear and Nonlinear Theory for Trawler Form at Zero Forward Speed ($L/\lambda = 0.75$).

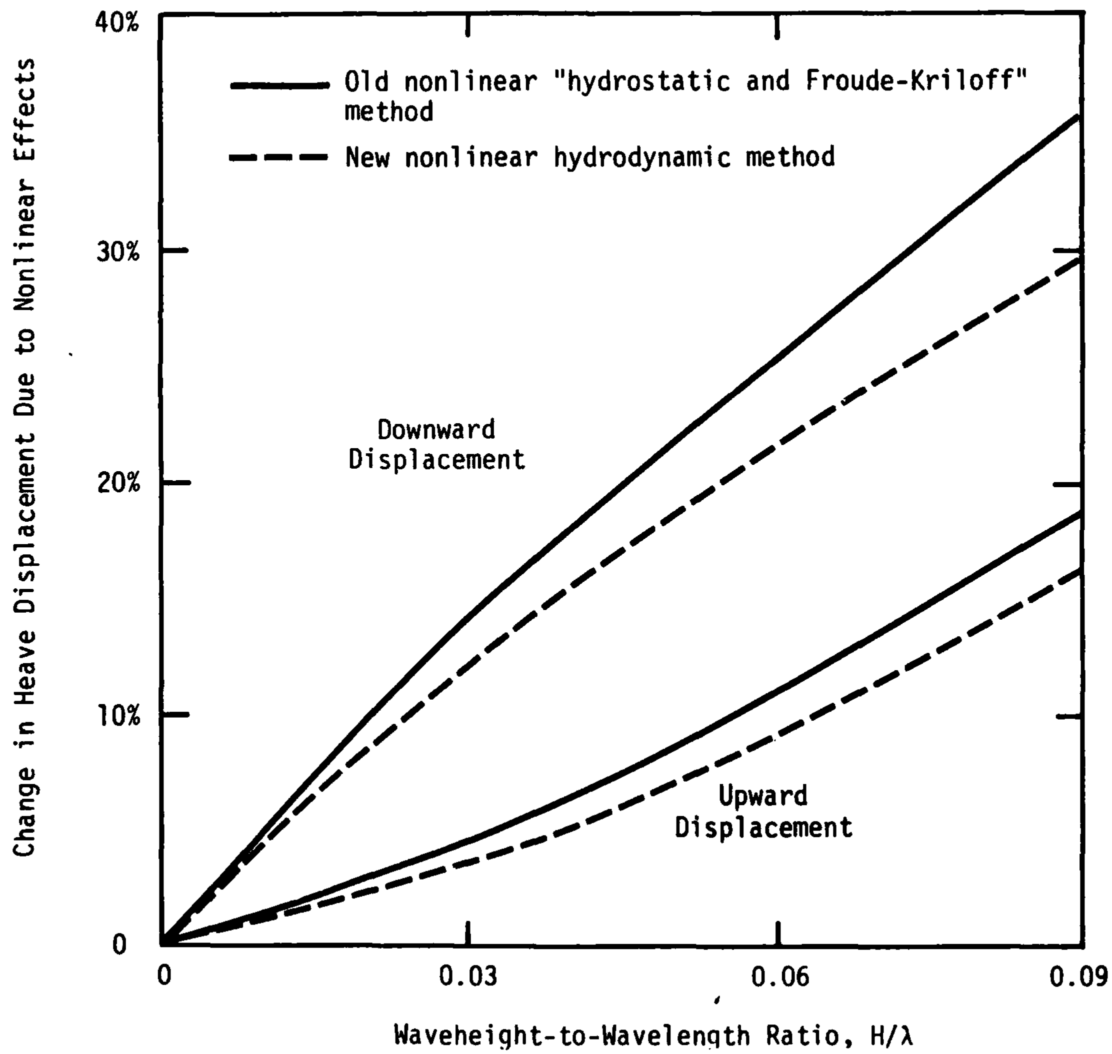
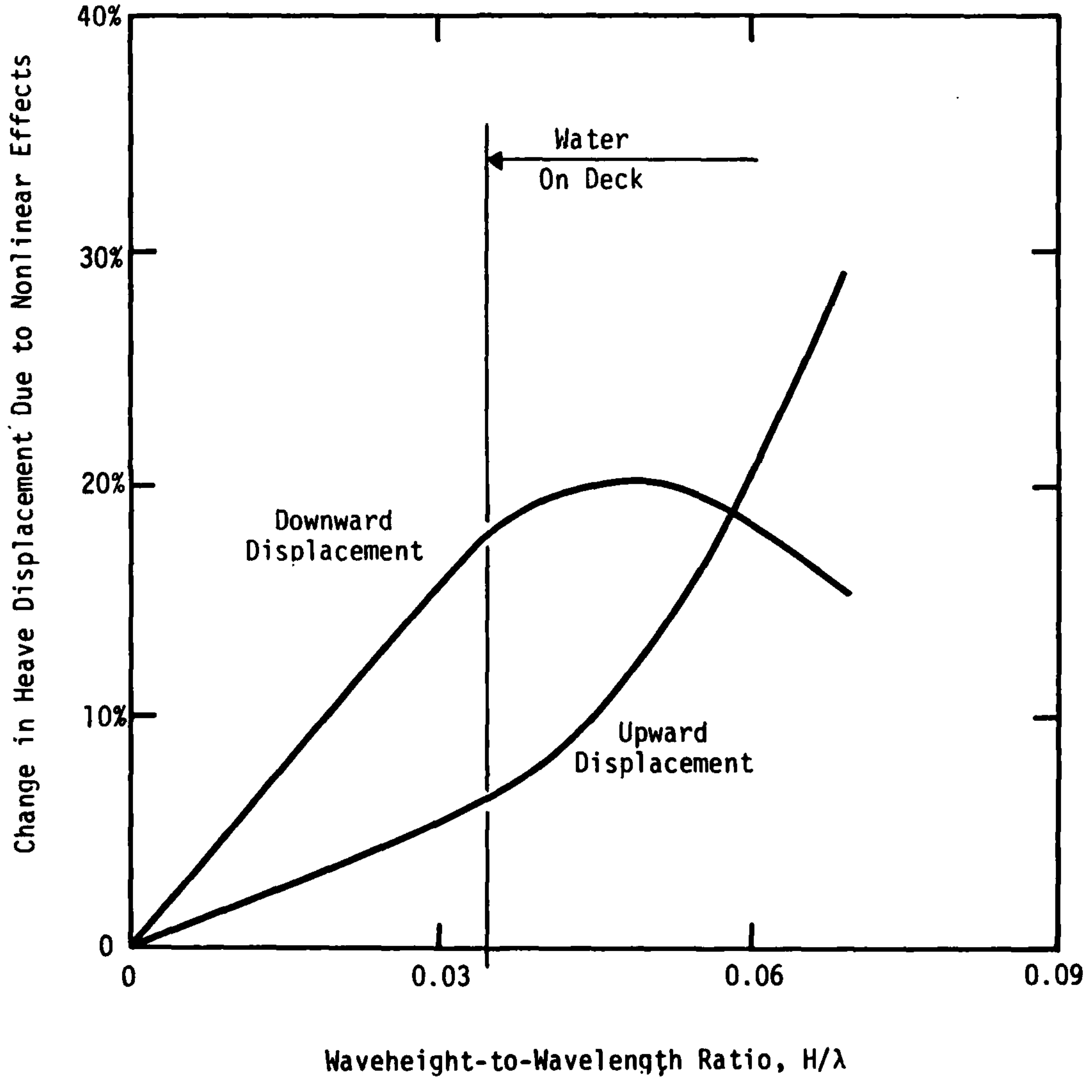


Figure 7: Differences in Heave Displacements Between Linear and Nonlinear Theory for Series 60, $C_B = 0.70$, at Zero Forward Speed ($L/\lambda = 0.75$).



Section 5

CONCLUDING REMARKS

The results obtained by the two computer codes for predicting non-linear large-amplitude motions for ships in beam seas and in head and following seas have been found in the linear range to agree well with linear frequency-domain strip theory. For steep waves, it has been found that there are large differences between the nonlinear method and the linear theory. Further investigations are needed in order to determine the accuracy of the nonlinear effects determined by this method, but the results clearly demonstrate that nonlinear effects are of significant magnitude for large amplitude motions.

It is strongly believed that improved accuracy in the nonlinear range can be achieved by including the nonlinear effects for the added-mass, damping, and diffraction terms in addition to the restoring and Froude-Kriloff forces.

Section 6

REFERENCES

Chang, Ming S., "Computations of Three-Dimensional Ship Motions with Forward Speed," Second International Conference on Numerical Ship Hydrodynamics, University of California, Berkeley, California (1977).

Paulling, J. R., and Paul D. Wood, "Numerical Simplification of Large Amplitude Ship Motions in Astern Seas," SNAME Technical and Research Symposium S-3, Seakeeping 1953-1973, Webb Institute (1974).

Salvesen, Nils, "Ship Motions in Large Waves," Symposium on Applied Mathematics dedicated to the late Prof. Dr. R. Timman, Delft, University Press (1978).

Salvesen, Nils, E. O. Tuck, and O. Faltinsen, "Ship Motions and Sea Loads," SNAME Transactions, Vol. 78 (1970).

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